The DUNE vertical drift TPC

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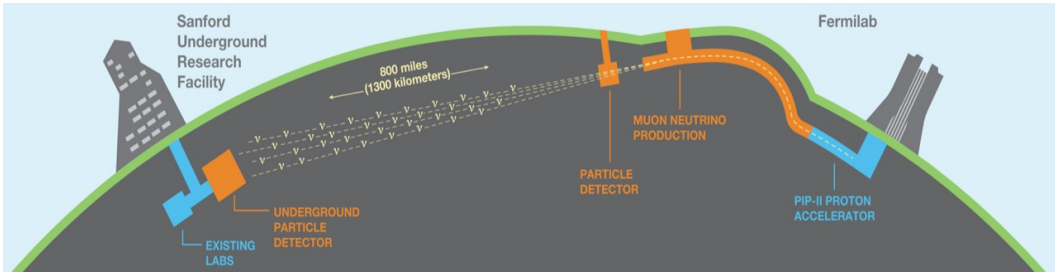
NuFACT 2022

Deep Underground Neutrino Experiment (DUNE)

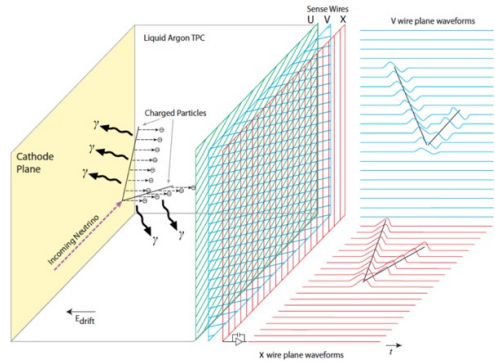
- Collaboration of over 1300 scientists and engineers from 37 countries and CERN
- 1.2 to 2.4 MW neutrino beam with a baseline of 1300 km to far detectors 1.5 km underground



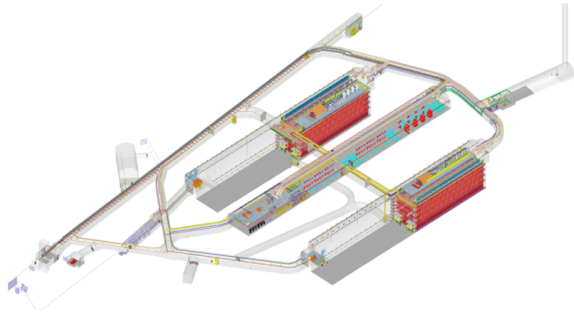
- Precision neutrino physics:
  - Measure neutrino hierarchy
  - Measure neutrino oscillation parameters including δ_{CP}
- But also supernova neutrinos, solar neutrinos, BSM and much more!

Liquid Argon TPCs

- Liquid Argon (LAr) provides a dense, pure medium with prompt scintillation for triggering (using separate photo-detectors), allowing the construction of kt-scale detectors, while being much more abundant and affordable than Xenon
- LAr Time Projection Chambers (TPCs) offer fine-grained (mm) three-dimensional tracking and total absorption calorimetry, which allows identifying particles via energy loss and topology



The DUNE far detectors



- The baseline technology for the first DUNE far detector (FD) module is a horizontal-drift single-phase LAr TPC built using wire-chamber technology, as used for ICARUS, MicroBooNE
- Single-phase Vertical Drift (VD) was chosen as the technology for FD2
- With 17.5 kt each, the DUNE FD modules will be the largest LAr TPCs ever built
- Phased approach foreseen, with FD1 and FD2 for Phase I, and two more FDs for Phase II (technology R&D ongoing)

Evolution of ProtoDUNE detectors

- Since 2018 the two ProtoDUNE cryostats were used to test the DUNE FD technologies
  - ProtoDUNE-SP validated the horizontal drift (HD) technology of FD1
  - ProtoDUNE-DP tested ambitious dual-phase technology for improved signal amplification, simpler construction and a longer drift-length
- The ProtoDUNE detectors demonstrated very good LAr purity,
  - allowing for a long 6.5 m drift distance
  - and resulting in excellent S/N
    → gain in gaseous phase is not needed
- Advantages of ProtoDUNE-DP inspired single-phase VD technology

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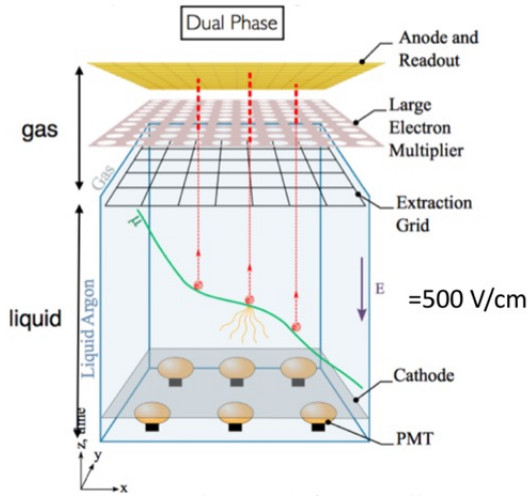
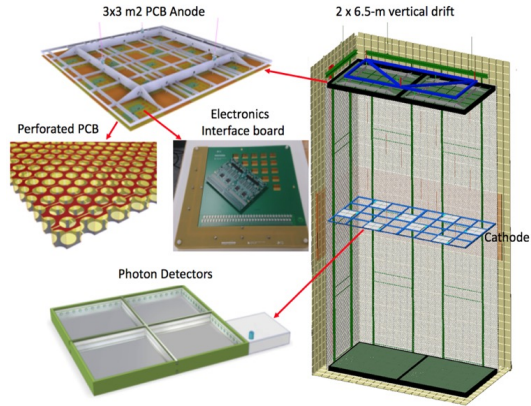


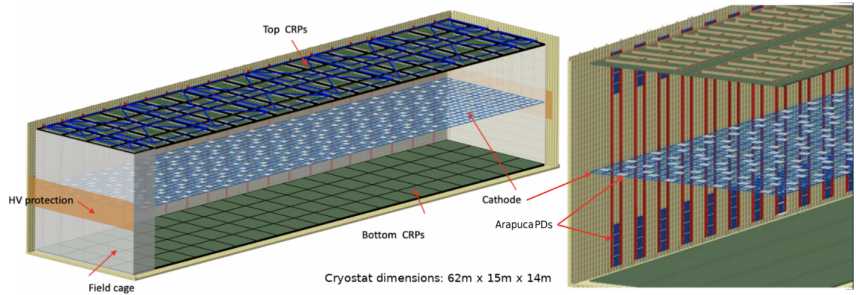
The Vertical Drift concept

- Take best properties of both ProtoDUNE detectors for an improved *single-phase* TPC
- Shared cryostat design with first FD module
- Anode of stacked segmented and perforated printed circuit boards (PCBs) with etched electrodes
  - mechanically robust and modular for easy assembly
  - mass producible
- Cathode suspended at mid-height
- Photon detectors (X-ARAPUCA) embedded in the cathode and cryostat walls for timing and triggering



For more information on simulation studies, see talk by Nitish Nayak

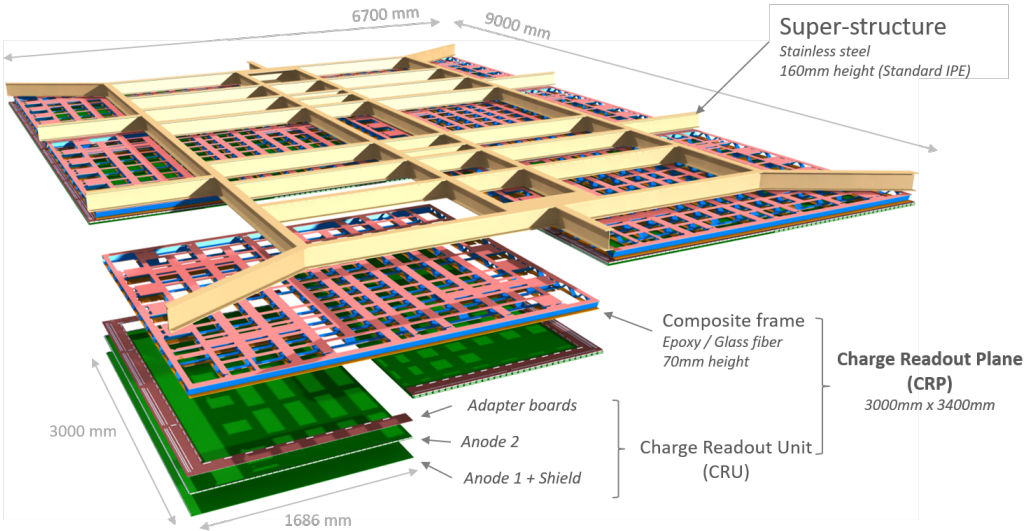
DUNE FD2 VD



Layout of Vertical Drift FD module

- Final 17 kt FD2 VD will have 2×80 (top and bottom) Charge Readout Planes (CRPs) (with 3.4 m $\times$ 3 m each)
- FD component mass production should start in 2024

Charge Readout Planes (CRPs) (top plane configuration)



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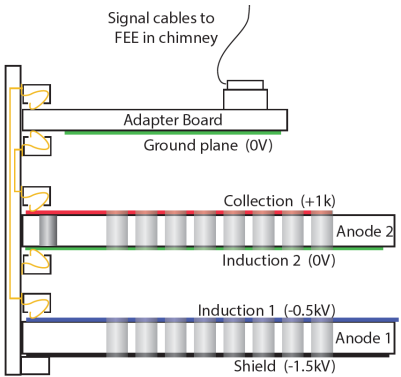
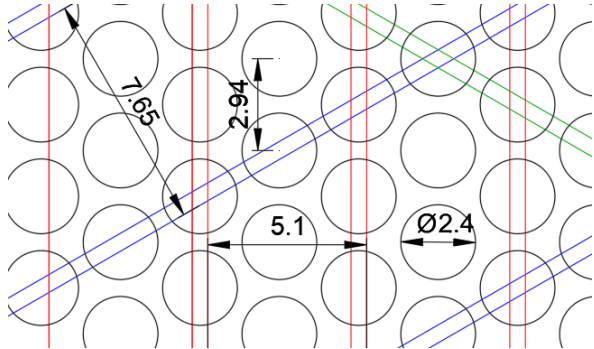
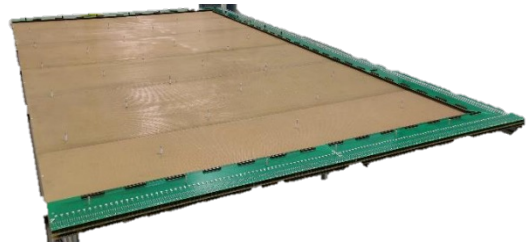




Charge readout electronics

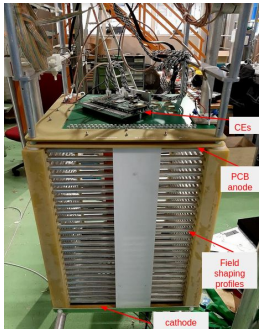
- Bottom readout electronics on cryostat floor, design shared with the FD-HD
- Attached directly to CRP



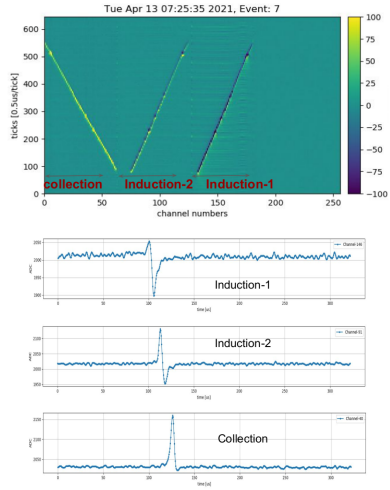
- Top readout electronics fully accessible from the top allows for maintenance/upgrade of electronics while the detector is cold
- Evolution of ProtoDUNE-DP electronics

Successful proof of concept: The 50 l

$32 \times 32\ \mathrm{cm}^2$ prototype TPC built at CERN to test hole-sizes, strip pitch, signal shapes and energy resolution using cosmic muons and a ^{207}Bi source in several runs from 2020 to 2022

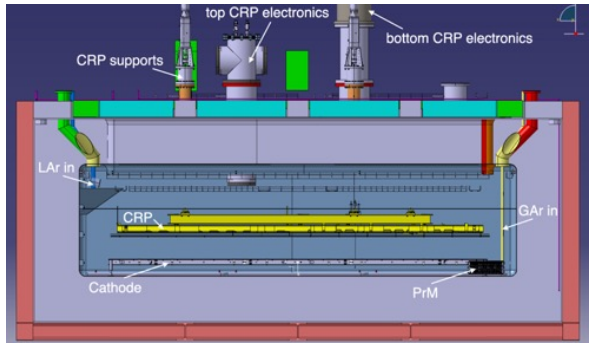


- Different PCB configurations tested:
  - Single two-view PCB
  - Two stacked PCBs (three views + shield layer)
- First test of edge connectors for the Module-0 CRPs
- Uses bottom readout electronics



Full CRP prototype: Cold-box

- The $4 \times 4 \times 1\,\mathrm{m}^3$ NP02 cold-box at the CERN neutrino platform was refurbished in order to test full-scale CRP modules, the cathode and the photon detection system at cold with a drift distance of about 20 cm
- Half of the first CRP, built in 2021, is instrumented with top, half with bottom electronics to test both readout electronic systems



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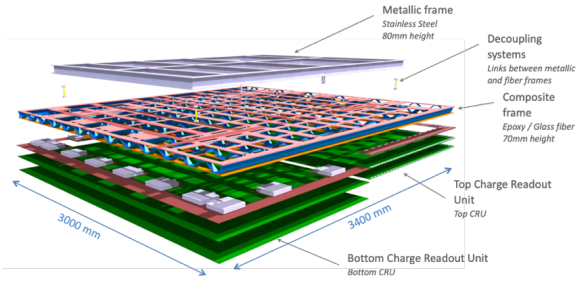
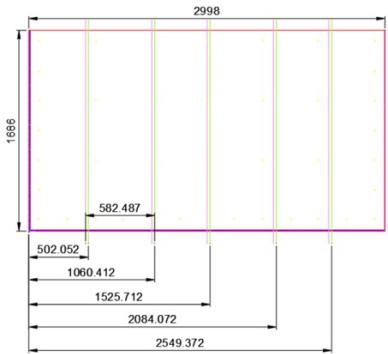


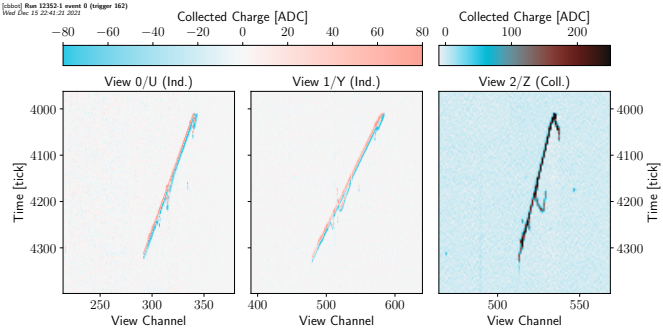
Aside: PCB glueing and silver-printing



- Due to manufacturing constraints, each anode panel has to be assembled from 6 segments, which are glued together with epoxy in a half-lap configuration
- Channels are bridged between segments using screen-printed conductive-ink connections

Cold-box Results

- CRP design validated at cold and gluing/interconnection of segments demonstrated.
- Two runs with large samples of $\mathcal{O}(10^6)$ triggers each were taken in Nov and Dec 2021, with full analysis in progress, with good tracks seen in both readout systems
- Excellent signal-to-noise ratio



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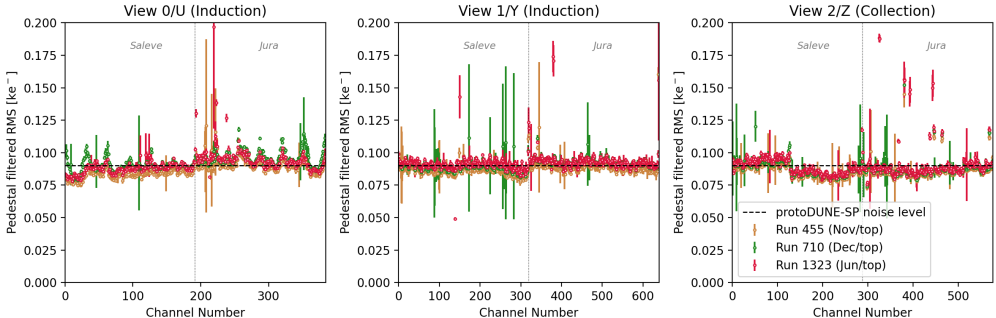
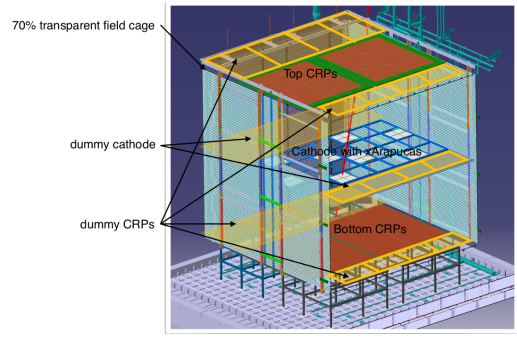


ProtoDUNE-VD

- NP02 ProtoDUNE cryostat will be re-instrumented as Module-0 of the FD-VD for early 2023, with dedicated test beams and cosmic runs in 2023 and 2024
- Several more cold-box runs foreseen this year to test:
  - the final strip orientation ($\pm 30°$, $90°$),
  - edge connectors and homogeneous top/bottom modules,
  - and for testing the CRPs before integration into the Module-0
- First CRP for the Module-0 was just tested in the cold box two weeks ago



Conclusion

- The Vertical Drift technology aims to unite the best features of both ProtoDUNE technologies for the second DUNE far detector.
  - High performance and signal to noise
  - Mechanically robust and simple to assemble
- The prototyping is progressing well and the first parts of the Module-0 are assembled and being tested
- Full Module-0 foreseen for early 2023, on track for DUNE Phase I